MATHEMATICS DEPARTMENT
RESEARCH SUMMARIES AY 2005

## CARLOS F. BORGES – *Associate Professor*

Research Project Summary
**TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES**
C. F. Borges, Associate Professor of Mathematics
Sponsor: Unfunded

**Objective**: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

**Summary**: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. This year I have focused on rapid algorithms for computing the QR decomposition of a generalization of the Vandermonde matrix. After a good deal of effort I have concluded that these algorithms lead to an unacceptable loss of accuracy. My next avenue of research will be to extend the techniques I have already developed to more general two-dimensional spline surfaces.

I attempted to get some funding for this work by applying it to a ship tracking problem of interest to the Coast Guard (related to Homeland Security) but was unsuccessful.

**DOD Key Technology Area**: Scientific Computation

**Keywords**: Curve Fitting, Data Compression, and Approximation Theory.

Research Project Summary
**Basic Algorithms for Green's Matrices**
C. F. Borges, Associate Professor of Mathematics
Sponsor: Unfunded

**Objective**: To develop a set of basic algorithms for Green's matrices.

**Summary**: This effort involved the development of a number of basic algorithms for working with Green's matrices. I developed an alternative proof of the relationship between Green's matrices and their inverses. This proof leads to a uniform development of a number of fundamental algorithms. I developed elegant algorithms for inversion, Cholesky factorization, and a group of extensions on the Quotient-Difference algorithm for eigenvalue computations (starting with a straightforward Cholesky LR algorithm and ending with a cancellation free variant of the orthogonal QD algorithm).

**DOD Key Technology Area**: Scientific Computation

**Keywords**: Linear Algebra, Eigenvalues.

## DAVID CANRIGHT – *Associate Professor*

Research Project Summary
**COMPACT S-BOX FOR THE ADVANCED ENCRYPTION STANDARD**

**David Canright, Associate Professor**
**Department of Applied Mathematics**
**Sponsor: NPS workload reduction support**

**OBJECTIVE:** To develop an implementation of the S-Box (byte substitution) step in the Advanced Encryption Standard (AES), optimized to minimize the circuitry needed for ASICs applications of AES.

**SUMMARY:** This work grew out of a project in 2004 to implement AES using Virtex II field-programmable gate arrays (FPGAs); memory constraints in this system precluded a fully pipelined implementation of AES using a table lookup approach for the crucial S-Box step. Instead, a direct calculation of the S-Box was developed, using subfields for the Galois arithmetic, in what has been termed the "tower-field" approach to Galois inversion. Different alternatives in each subfield result in 432 different implementations of this method. From these, the most compact was identified and optimized. This allowed a fully pipelined AES on a single Virtex II chip; the same approach may be useful for other hardware-limited implementations of AES, e.g., smart cards.

In 2005, the basis-change matrices for several more of the 432 cases were fully optimized, strengthening the conclusion that the specific case chosen was the best possible. Also, a further optimization at the logic-gate level, substituting NORs for some NANDs and XORs was incorporated. The final S-Box circuit was 20% smaller than the most compact previously known. These results were detailed in a revised version of the previous Technical Report, and presented at the CHES2005 conference in Edinburgh, Scotland, with the paper appearing in the conference proceedings. Since then, two different research groups have asked to use this implementation, and several other researchers have expressed interest.

**PUBLICATIONS:**

D. Canright, "A Very Compact Rijndael S-box (revised)," Naval Postgraduate School Technical Report, NPS-MA-05-001, May 2005.

D. Canright, "A Very Compact S-box for AES," Workshop on Cryptographic Hardware and Embedded Systems (CHES2005), Lecture Notes in Computer Science 3659, pp.441-455, Springer-Verlag.

**PRESENTATIONS:**

D. Canright, "A Very Compact S-box for AES," Workshop on Cryptographic Hardware and Embedded Systems – CHES2005 (7th International Workshop), Edinburgh, UK, 29 August – 1 September 2005.

**KEYWORDS:**

cryptography, AES, Rijndael, S-box.

Research Project Summary

## Experiments with the SRC-6e FPGA Computer

**Hal Fredricksen, Professor**
**David Canright, Associate Professor**
**Chris Frenzen, Associate Professor**
**Department of Applied Mathematics**
**Douglas Fouts, Professor**
**Jon Butler, Professor**
**Department of Electrical and Computer Engineering**
**Sponsor: National Security Agency**

**OBJECTIVE:** The objective of the research is to consider various mathematical algorithms for their suitability as programmed on the SRC6-e FPGA computer. The concept was suggested by the sponsor and various proposed algorithms were studied by the participants. Specific tasks of interest include: (1) genetic algorithms for string generation/recognition applications; (2) mathematical function calculation using piecewise-defined approximations; (3) multiprecision integer arithmetic primitives for various information security applications.

***See the* FAR *of Professor Hal Fredricksen for the Project Summary relating to the first two objectives; the summary below relates to the last objective.***

**SUMMARY:** The specific reconfigurable computer chosen for this work is an SRC-6E from SRC Computer Corp. The reconfigurable part of this system uses Virtex II field-programmable gate arrays (FPGAs). This system has the advantage of including a C-compiler that can be used to reconfigure the hardware in the FPGAs. However, this approach introduces severe constraints in memory access for algorithms implemented on the FPGAs. After some preliminary background research, the arithmetic primitive chosen for implementation was multiprecision integer multiplication, using the Karatsuba algorithm. However, a complete working implementation on the FPGA was not achieved in the research period.

**KEYWORDS:**

multiprecision integer arithmetic, FPGA, Karatsuba.

**DONALD A. DANIELSON – *Professor***

ASTRODYNAMICS RESEARCH - 2005
D. A. Danielson, Professor
Department of Applied Mathematics
Sponsor: Unfunded

OBJECTIVE:

Apply astrodynamics theory to problems of interest to the military.

SUMMARY:

In February Prof. Mike Ross and and Prof. Danielson submitted a multiyear proposal to the NRO, and in July they traveled to Chantilly, VA, to discuss research topics with scientists at the NRO and Aerospace Corporation. This fall their thesis student LCDR Drew Carlson began his thesis work on optimal orbit maneuvers with electrodynamic tethers.

Also this year, Prof. Danielson teamed up with Prof. Terry Alfriend to work in the area of satellite orbit determination. In September their thesis student CDR Mike Thrall received the MS in Space Systems Operations. He showed the improvement in orbit determination obtained by adding angles-only observations from a Raven telescope to ranging data for the Sirius3 satellite. Prof. Danielson's main contribution was to advise him on the orbital mechanics.

THESIS DIRECTED:

Thrall, M., "Orbit Determination Using A Raven Telescope For Highly Eccentric Orbits", Master's Thesis, Naval Postgraduate School, September 2005.

## FARIBA FAHROO – *Associate Professor*

*Leave of Absence*

## HAL FREDRICKSEN – *Professor*

Experiments with the SRC-6e FPGA Computer
Harold Fredricksen
(Research in collaboration with Douglas Fouts, ECE and
Jon Butler, ECE, David Canright, MA and Chris Frenzen, MA)
Department of Applied Mathematics
Sponsor: National Security Agency

OBJECTIVE: The objective of the research is to consider various mathematical algorithms for their suitability as programmed on the SRC6-e FPGA computer. The concept was suggested by the sponsor and various proposed algorithms were studied by the participants.

SUMMARY: Certain of the algorithms were considered to be well suited to computation on the unique mainframe. Others were determined to be less suitable. Professor Fouts is continuing his work with various signal processing algorithms. Professors Butler and Frenzen are reporting on their progress on algorithms related to fast function evaluations separately. Professor Canright will post his research report separately. My results, along with support from two student efforts, was devoted to algorithms to generate de Bruijn cycles in a novel way. Two papers and a oral report were presented to the sponsor.

PUBLICATION:

Reports:

1. Steve Huntsman, Peter Eacmen (with David Wood and Hal Fredricksen), de Bruijn Spaces, the Necklace Function and a String Sampling Protocol for Implementation on a Reconfigurable Computing Architecture, submitted to the sponsor.
2. Peter Eacmen, Usage analysis of the SRC FPGA Development Platform, submitted to the sponsor.

Proceedings:

1. Hal Fredricksen & Steve Huntsman, A String Sampling Protocol for de Bruijn Sequence Generation, presented at NSA Conference on SRC Computing, June 2005.

## CHRIS FRENZEN – *Associate Professor*

**Experiments Using Prototype Recon Machine**
Chris Frenzen, Associate Professor
Department of Applied Mathematics
Sponsor: National Security Administration

OBJECTIVE: **To produce efficient designs for logic circuits that realize numeric functions, such as $f(x) = sin(x)$. The design is easily adapted to a range of commonly used functions, including trigonometric functions, $2^x$, $\log x$, entropy function, sigmoid function, and Gaussian function.**

**SUMMARY:**

**High-Speed Numeric Function Generators and Content-Addressable Memory (CAM) Design:** We develop high-speed numeric function circuits that produce a binary encoding of $f(x)$ given a binary encoding of $x$. Such circuits are useful in digital signal processing applications and computation environments. For example, the CORDIC algorithm is a well-known method for computing trigonometric and other functions. Our approach is to develop the design of a circuit realizing $f(x)$ given the desired precision. We have shown that such designs have reasonable size using LUT (LookUp Table) cascades. We have extended these results to show that they are applicable in designing low-power content-addressable memory (CAM). Our CAM designs are also useful in more sophisticated numeric function generators. The paper: **C. Frenzen**, T. Sasao, and J. T. Butler, "The tradeoff between circuit complexity and approximation error in high-speed numeric function realization," is in preparation.

**PRESENTATION:**

Frenzen, C, ``Numeric Function Generators", National Security Agency, Fort Meade, MD, 20 June 2005.

**KEYWORDS** digital systems, compact circuits, computer-aided design tools, sum-of-products expressions.

## RALUCCA GERA – *Assistant Professor*

DOMINATOR COLORINGS AND SAFE CLIQUE PARTITION
(with Craig Rasmussen, Naval Postgraduate School; Steve Horton, United States Military Academy)

Objective: To study dominator colorings for particular classes of graphs. Also, we introduced the new concept of safe clique partition which was also studied in the second part of the project.

Summary: Given a graph G, the dominator coloring problem seeks a proper coloring of G with the additional property that every vertex in the graph dominates an entire color class. The safe clique partition problem seeks a partition of the vertices of a graph into cliques with the additional property that for each vertex v, there is a clique that has no element in the open neighborhood of v. We typically seek to minimize the number of color classes or cliques used, respectively. In this project, we studied these two concepts and considered the relationship between them.

Keywords: labeling, vertex cover, independence.

DOD Key Technology Area: Information Systems Technology
AMS Subject Classification: 05C15, 05C69.

Preliminary Results on the Minimum Sum Vertex Cover Problem
(with Craig Rasmussen, Pantelimon Stanica, Naval Postgraduate School; Steve Horton, United States Military Academy)

Objective: To study the minimum sum vertex cover for regular graphs. In this project, we give general bounds (some are tight) for msvc cost on several classes of graphs. In particular, we study the msvc problem for the generalized Petersen graphs.

Summary: Let G be a graph with the vertex set V (G), edge set E(G). A vertex labeling is a bijection f : {1, 2, . . . , |V (G)|} ! V (G), and a vertex cover labeling is f(e) = min{f(u), f(v)}. The min-sum vertex cover (msvc) is a vertex labeling that minimizes the sum μs = Pe2E(G) f(e), where μs is called the min-sum vertex cover number or the cost. We present results on msvc for several graph classes.

Keywords: coloring, labeling, vertex cover, independence.

DOD Key Technology Area: Information Systems Technology

AMS Subject Classification: 05C15, 05C69.
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## WILLIAM B. GRAGG – *Professor*

Research Project Summary
**Research in Computation**
William B. Gragg, Professor of Mathematics
Sponsor: Unfunded

**Objective**: I have no funded research projects. This is not to say that I do not continually try to do (high quality) research in scientific computing. See my publication list which is part of my CV. There are always more problems than solutions, but the ones that last are the ones that are elegantly solvable. For instance, in a paper dedicated to me on my 65th birthday, Lothar Reichel et. al. showed how to compute the zeros of linear combinations of polynomials orthogonal on the real line, or the unit circle in the complex plane, in O(n^2) operations. The first had been an open problem for many years. The solution was elegant and simple. The solution applicable to the usual polynomial problem, when the polynomial is expressed as a linear combination of the powers, depends strongly on my "uhqr" (unitary Hessenberg QR) algorithm. These algorithms are fundamental, and brand new (soon to appear in J Comput Appl Math)!

## WEI KANG – *Associate Professor*

**COOPERATIVE CONTROL OF MULTI-SETP MANUFACTURING SYSTEMS**
**Wei Kang, Associate Professor**
**Department of Applied Mathematics**
**Sponsor: Intel Corp**

**OBJECTIVE:** The objective of the research is to develop design, analysis, and simulation of high volume manufacturing with multiple process steps. The goal is to develop control architecture and feedback algorithms to achieve cooperative control of semiconductor manufacturing process with multiple processing steps.

**SUMMARY:** Working with engineers from Intel, we successfully identified the variables and steps that are critical to the overall performance of the multi-step manufacturing process. Based on real manufacturing data, a three layer cooperative control architecture is developed. Mathematical model is developed for each layer of the process based on real data and important multiple input and output parameters. Cooperative control law is development to optimize the cost functions, under the constraints and based on real-time information. A large number of Monte-Carlo simulations were carried out to verify the efficiency of the cooperative controller. Simulations based on real data of Intel flash product show that the yield is improved significantly, from 10% to 30%, depending on the number of process steps under control.

**PSEUDOSPECTRAL OPTIMAL CONTROL OF NONLINEAR SYSTEMS**
**Wei Kang, Associate Profess**
**(Research collaboration with Professor I. Michael Ross, MAE)**
**Department of Applied Mathematics**
**Sponsor: The Secretary of the Air Force**

**OBJECTIVE:** The objective of the research is to develop practical methods to solve highly nonlinear optimal control problems, and to prove the efficiency of the method by proving the feasibility and convergence. The fundamental concept in the approach is based on the Pseudospectral approximation theory of numerical computation, and nonlinear programming for complicated optimization problems.

**SUMMARY:** For some important families of nonlinear systems, the feasibility and convergence of the Pserdospectral optimal control method are proved. In addition, the covector mapping theorem, an important result

that bridges the optimal state in a control system with the necessary conditions of optimal control, is proved for general nonlinear systems.

**PUBLICATION:**

**Journal Papers:**

1. B. Hamzi, W. Kang and A. J. Krener, The Controlled Center Dynamics, SIAM J. Multiscale Modeling & Simulation, Vol. 3, No. 4, pp838-852, 2005.
2. W. Kang, M. Song, and N. Xi, Bifurcation Control, Manufacturing Planning, and Formation Control, ACTA Automatica SINICA, Vol. 31, No. 1, pp. 84-91, 2005.
3. W. Kang, N. Xi, J. Tan, Y. Zhao, and Y. Wang, Coordinated Formation Control of Multiple Nonlinear Systems, J. Control Theory and Applications, to appear.
4. W. Kang, Moving Horizon Numerical Observers of Nonlinear Control Systems, IEEE Trans. on Automat. Contr., to appear.
5. Q. Gong, W. Kang and I. M. Ross, A Pseudospectral Method for the Optimal Control of Constrained Feedback Linearizable Systems, IEEE Transactions on Automatic Control, to appear.
6. B. Hamzi, A. J. Krener, W. Kang, The Controlled Center Dynamics of Discrete Time Control Bifurcations, Systems & Control Letters, to appear.

**Conference Proceedings:**

1. W. Kang and J. Mao, An Adaptive Model for the Control of Critical Dimension in Photolithography Process, Proc. IEEE Conference on Decision and Control, December, 2004.
2. W. Kang and J. Mao, Robust control of lithorgraphic process in semiconductor manufacturing, SPIE Symposium on Microlithography, San Jose, January, 2005.
3. W. Kang, Z. J. Mao, Robustness of process controllers for semiconductor manufacturing, The 9th World Multi-Conference on Systemics, Cybernetics and Information, Orlando, FL, July, 2005, pp. 229-234.
4. B. Hamzi, W. Kang, and A. J. Krener, Stabilization of Discrete Time Systems with a Fold or Period-Doubling Control Bifurcation, IFAC World Congress, Praha, Spain, 2005.
5. Q. Gong, I. M. Ross, and W. Kang, A Pseudospectral Observer for Nonlinear Systems, Proc. AIAA GNC Conference, San Francisco, AIAA2005-5845, August, 2005.
6. Q. Gong, W. Kang and I. M. Ross, A Pseudospectral Method for the Optimal Control of Constrained Feedback Linearizable Systems, Proc. IEEE Conference on Control Applications, Toronto, Canada, pp. 1033-1038, 2005.
7. Q. Gong, I. M. Ross, W. Kang and F. Fahroo, Convergence of pseudospectral methods for constrained nonlinear optimal control problems, Proc. 8th IASTED International Conference on Intelligent Systems and Control, Cambridge, October, 2005.
8. W. Kang, Numerical Observers of Control Systems Using Computational Optimization Methods, Proc. 8th IASTED International Conference on Intelligent Systems and Control, Cambridge, October, 2005.
9. W. Kang, Q. Gong and I. M. Ross, Convergence of Pseudospectral Methods for a Class of Discontinuous Optimal Control, Proc. IEEE Conference on Decision and Control, Seville, Spain, December, 2005.

**Intellectual Property**

1. J. Mao and W. Kang, Robust L-order Feedback CD (critical dimension) Controller for Photolithographic Process Control, Trade Secret, Intel Corp., 2005.

**PRESENTATION:**

1. W. Kang, Cooperative Control of Multi-Process Steps in Semiconductor Manufacturing, Invited Speaker, Intel High Volume Manufacturing Research Committee Speaker Series, April 22, 2005.

**BENY NETA– *Professor***

A Study of Lateral Boundary Conditions for The NRL's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)

**B. Neta, Professor of Mathematics**
**Sponsor**: NPS

**OBJECTIVES:** The treatment of lateral boundaries in regional models has been a perennial problem since the early days of numerical weather prediction. In a limited-area model the lateral edges are not physical boundaries of the flow but constitute artificial constraints imposed by computational considerations. Hence they do not have a physical counterpart. We must impose conditions at these artificial boundaries in order to solve the problem in an efficient and accurate manner.
We propose here to continue our work on high order non-reflecting boundary conditions for the dispersive Klein-Gordon equation. We intend to extend our new schemes to the nonlinear shallow water equations.
**Keywords**: Mesoscale, limited-area model, perfectly matched layers, COAMPS.
**DoD Key Technology Areas**: Software.

**PUBLICATIONS**

1. V. van Joolen, B. Neta, and D. Givoli, "High-Order Higdon-Like Boundary Conditions for Exterior Transient Wave Problems," *International Journal Numerical Methods in Engineering*, 63, (2005), 1041-1068.

**THESIS DIRECTED**

P-Stable High Order Super Implicit and Obrechkoff Methods

**B. Neta, Professor of Mathematics**
**Sponsor**: NPS

**OBJECTIVES:** Two classes of methods for the numerical solution of periodic initial value problems are discussed. These are super-implicit methods due to Fukushima and Obrechkoff schemes. The advantage of Obrechkoff methods is that they are high order one-step methods and thus will not require additional starting values. On the other hand they will require higher derivatives of the right hand side. In case the right hand side is very complex, we may prefer super-implicit methods. We develop super-implicit P-stable method of order 12 and Obrechkoff method of order 18.

**Keywords**: Obrechkoff, super implicit, periodic initial value problems.
**DoD Key Technology Areas**: Software.

**PUBLICATIONS**

1. B. Neta, P-stable Symmetric Super-Implicit Methods for Periodic Initial Value Problems, *Computers and Mathematics with Applications*, **50**,(2005), 701-705.
2. B. Neta, P-stable High Order Super-Implicit and Obrechkoff Methods for Periodic Initial Value Problems, *Computers and Mathematics with Applications* accepted for publication.

## GUILLERMO OWEN – *Professor*

a. Mathematical Models of Search.

This project is funded through the Department of Defense Analysis. Owen and Professor Gordon McCormick of DA are co-Principal Investigators.
Professors McCormick and Owen have developed game-theoretic models for search; on this topic, one article was submitted for publication.

Article Submitted:

(G. McCormick and G. Owen): "Tracking a Moving Fugitive," submitted to *Computers and Operations Research*.

Research reports:

(G. McCormick and G. Owen): "Deceptive Signals."

(G. McCormick and G. Owen): "Noisy searches."

Colloquium presentation:
(G. McCormick and G. Owen): "Tracking a Moving Fugitive," Dutch Naval Academy, Den Helder, Netherlands, March 1, 2005.

b. Game-Theoretic Approaches to Terrorist and Insurgent Networks

This project is funded through the Department of Defense Analysis. Owen and Professor Gordon McCormick of DA are co-Principal Investigators.

Article Submitted:

(M. Koster, R. Lindelauf, I. Lindner and G. Owen): Mass Mobilization under Uncertainty of Information," submitted to *Mathematical Social Sciences*

Research reports:

(I. Lindner and G. Owen): "Endogenous Formation of Coalitions"

(M. Koster, I. Lindner, and G. Owen): Terrorist Targeting, Information, and Coalition Behavior

(M. Koster, R. Lindelauf, I. Lindner, L. Bostick, and G. Owen): "A Catlaog of Terrorist Organizations."

c. Theory of Games and Applications

This is an unsponsored project, on which Professor Owen has worked with mathematicians at the Complutense University in Madrid, Spain, and at the University of Utrecht, Netherlands. He has published an article dealing with centrality in social networks, and submitted a second one for publication. He also published an article on reduced games and consistent values.

Articles accepted:

(C. Manuel, E. Gonzalez, F. Gomez, M. del Pozo, G. Owen and M. Saboya): "Cohesiveness in Graphs ," accepted by *Annals of Operations Research*, 2005

Articles submitted:

(I. Lindner and G. Owen): "Cases where the Penrose Limit Theorem does not hold," submitted to *Mathematical Social Sciences*

(B. N. Grofman, I. Lindner and G. Owen): "Modified Power Indices for Indirect Voting," submitted to a volume in honor of Manfred Holler

## CRAIG RASMUSSEN – *Associate Professor*

**The Dominator Coloring and Safe Clique Partition Problems**
Craig Rasmussen, Associate Professor
Department of Applied Mathematics
Funding Agency: NPS (workload funds)
With Ralucca Gera (NPS) and Steve Horton (USMA)

**Objective**: To either compute or bound the Dominator Coloring numberand/or the Safe Clique Partition number for various graph classes.

**Summary**: Given a graph G, the dominator coloring problem seeks a proper coloring of G with the additional property that every vertex in V (G)dominates at least one color class. The dominator coloring number of G,denoted _d(G), is the least number of color classes in any dominator coloring of G. The safe clique partition problem is the complement of the dominator coloring problem, in the sense that the safe clique partition number of G is _d(G) = _(G), where G the complement of G. We anticipate one or more publications arising from this research.

**Keywords**: domination, chromatic number

**DoD Key Technology Areas**: Information Systems Technology

**The Minimum Sum Vertex Cover Problem**
Craig Rasmussen, Associate Professor
Department of Applied Mathematics
Funding Agency: none in 2005
With Ralucca Gera, Pantelimon Stanica (NPS),
and Steve Horton (USMA)

**Objective**: To discover both exact results and bounds for the minimum sum vertex cover of graphs in various classes.

**Summary**: The minimum sum vertex cover (**msvc**) number of a nonempty undirected graph G = (V,E) is defined as follows: The function f : V ! {1, 2, . . . , |V |} is an ordering of V , and g : E ! **Z**+ is defined by g(uv) = min{f(u), f(v)}. The msvc number is μs(G) = minPe2E g(e), where the minimum is taken over all orderings f. In general, **msvc** is NP-Hard. Application is to optimization of data migration schedules. We anticipate one or more publications arising from this research.

**Keywords**: labeling, vertex cover, independence.

**DoD Key Technology Areas**: Information Systems Technology

## CLYDE SCANDRETT – *Professor*

Research Project Summary
Reference/textbooks on Technology of Countering Sea Mines and on Technology of Countering Land Mines, IED's, and Booby Traps
C. Scandrett, Professor of Mathematics
Sponsor: Office of Naval Research

**Objective:** To prepare text/reference books on the emerging technologies that are applicable to Land Countermine (including Improvised Explosive Devices and Humanitarian Demining), and a second text applicable to Sea Countermine. Both books will be based upon the eleven (11) major scientific symposia and conferences in which Mr. Bottoms has had direct responsibilities in planning and organizing. This series began in April, 1995, and has included six international symposia at the Naval Postgraduate School, three Australian-American Conferences in Australia, and a major international conference in Europe at the Free University of Brussels

**Summary:** Editing and publishing of the texts were undertaken during FY05, employing the services of Mr. Al Bottoms, the first Mine Warfare Chair of the Naval Postgraduate School and originator of the Mine Symposia series, to produce and deliver over 200 three-volume sets of the texts to libraries and field offices worldwide.

**Publications**:

***Applications of Technology to Demining*** Part I, subtitled ***Landmine Countermeasures,*** volumes 1 and 2.
***Applications of Technology to Demining*** Part II, subtitled ***Naval Mine Countermeasures***

**Presentations:**
None.

DOD Key Technology Area: Sensors, Electronics, and Battlespace Environments and Weapons

Keywords: Mines, Mining, Undersea Warfare

**HONG ZHOU – *Assistant Professor***

**MATHEMATICAL MODELING OF NEMATIC LIQUID CRYSTALLINE POLYMERS AND NANOCOMPOSITES**

**Hong Zhou, Assistant Professor**
**Department of Applied Mathematics**
**Sponsor: Naval Postgraduate School**

**OBJECTIVE:** The specific objectives are to 1) study the mathematical modeling and computational framework for investigating flow-induced morphology and rheology of nematic liquid-crystalline polymers and nanocomposites; 2) to use the framework to study the morphology induced by shear flow and Poiseuille flow; and 3) to study the property enhancement induced by adding nanocomposites in polymeric flows.

**SUMMARY:** Macromolecular materials (e.g. liquid crystals), comprised of synthesized molecular elements in the form of rigid rods or platelets, are technologically important materials. They are widely employed in Air Force and NAVY products and are being explored for promising performance enhancements such as strength, thermal conductivity, and barrier properties. Notable examples are night vision devices, wavefront sensors and bulletproof vests. The macroscopic properties of polymer materials depend on both their structure and their liquid phase processing. Hong Zhou's work focused on the study of the flow-induced morphology and rheology. Issues for applied PDE's and numerical analysis were investigated. Her work provided some theoretical basis for understanding performance features of high performance nematic polymer materials and nanocomposites.

**PUBLICATIONS:**

1. Zhou, H., M.G. Forest, X. Zheng, Q. Wang, and R. Lipton,

``Extension-enhanced conductivity of liquid crystalline polymer nano-composites,'' Macromolecular Symposia, Vol 228, pp.81-89, 2005.

2. Zhou, H. and M.G. Forest, ``A numerical study of unsteady thermal glass fiber drawing processes,'' Communications in Mathematical Sciences, Vol 3, pp.27-45, 2005.

3. Zhou, H., H. Wang, M.G. Forest and Q. Wang, ``A new proof on axisymmetric equilibria of a three-dimensional Smoluchowski equation,'' Nonlinearity, Vol 18, pp.2815-2825, 2005.

4. Q. Wang, S. Sircar and Zhou, H., ``Steady state solutions of the Smoluchowski equation for nematic polymers under imposed fields,'' Communications in Mathematical Sciences, Vol 3, pp. 605-620, 2005.

**PRESENTATIONS:**

Zhou, H., ``Anchoring Distortions Coupled with Planar Couette & Poiseuille Nematic Polymer Flows'', Institute for Mathematics and its Applications (IMA) workshop ``Effective Theories for Materials and Macromolecules'', University of Minnesota, June 2005.

Zhou, H.,``Dynamics of Microstructure and Flow Interactions,'' Applied Mathematics Seminar, UC Berkeley, November 2005.